Brass Tacks

An in-depth look at a radio-related topic

Single sideband

You likely got your start in amateur radio on 2 meters, communicating with other hams through FM repeaters. If you decide to upgrade your license to General, you might discover the world of HF (high frequency), where its voice mode of operation becomes largely ***single sideband***, abbreviated *SSB*. Admittedly, however, Technician licensees can operate SSB on 10-meters, which is part of HF, and any radio amateur can operate SSB on 2 meters. But the larger world of voice communication for those who obtain the General class license and operate HF, is single sideband, the primary mode of operation.

In 1915, John Carson devised single sideband as a means to multiplex several phone calls together onto a single circuit. Right away, the US Navy began experimenting with SSB over radio. SSB required frequency stability and selectivity well beyond the capabilities of most AM receivers, which is why broadcasters have seldom used it. Amateur radio operators began serious experimentation with SSB shortly after World War II, and since 1957, single sideband has become the de facto standard for long-distance voice radio transmissions.

When you first get into HF, you might be surprised to hear that SSB isn't the quiet, clear sound of squelch and carrier squelch that you're used to on 2 meters FM. Because the remote signals you're hearing are often quite weak, if you were to enable the squelch while on HF, that will pretty much disable your audio, rendering the bands very silent. On SSB, you've now entered the world of near-constant atmospheric noise and permanent hiss.

What you're hearing is how radio *really* sounds like. If the other SSB station you're listening to is strong enough, it might be able to penetrate the noise well enough for you to make the contact. You might also be aware that you'll need to select LSB (lower sideband) or USB (upper sideband), depending on which band you're listening to. Fortunately, most of today's transceivers will select the proper sideband for you when you change bands, but you can still manually control that setting.

What SSB is

Besides being another "mode of operation", single sideband is a refinement of AM, or amplitude modulation, in that it requires less power and less bandwidth for a given transmission, and is therefore more efficient. The drawbacks of SSB, however, include somewhat more difficult receiver tuning and device complexity at both ends. Additionally, as was mentioned, its sound does take a little getting used to.

Probably the best way to describe SSB is to discuss techni-

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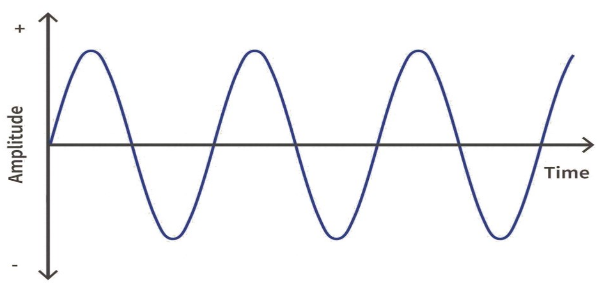
cally how it originates, and why we believe it's important to use on some bands and less important on others. It all starts with a simple signal, a sine wave of a selected frequency, known as the ***carrier***:

$$\mathbf{c(t) = Asin(2\pi f_c t)}$$

In this case, **A** is the amplitude (power) of the sine wave and $\mathbf{f_c}$ is the carrier frequency. The **t** is time, and tells us that this function is making the amplitude **A** change as time goes by. The resulting signal **c(t)** is pretty boring and might look like this on an oscilloscope:



Now, we mix in the sound of your voice, so that the carrier signal is modified or ***modulated*** by your voice. Instead of looking at every signal your voice is made of, let's consider it one tiny slice at a time, a cosine wave:

$$\mathbf{m(t) = Bcos(2\pi f_m t)}$$

B is the amplitude (power, or loudness) of your voice and $\mathbf{f_m}$ is the frequency (pitch) of your voice at that instant. And once again, this means the amplitude **B** changes with time. By the way, the cosine function swings both positive and negative, so add a 1 to both sides for the undermodulated case (not derived here) to keep the voice positive, and we have

$$\mathbf{1 + m(t) = 1 + Bcos(2\pi f_m t)}$$

Next, let's *mix* the two together, meaning *multiply* them, and call the result **y(t)**:

$$\mathbf{y(t) = c(t)[1 + m(t)] = Asin(2\pi f_c t)[1 + Bcos(2\pi f_m t)]}$$

$$\mathbf{y(t) = Asin(2\pi f_c t) + Asin(2\pi f_c t)Bcos(2\pi f_m t)}$$

Using the trigonometric identity **sinxcosy = ½[sin(x + y) + sin(x – y)]**,

$$\mathbf{y(t) = Asin(2\pi f_c t) + \tfrac{1}{2}AB\{sin[2\pi(f_c + f_m)t] + sin[2\pi(f_c - f_m)t]\}}$$

$$\mathbf{y(t) = Asin(2\pi f_c t) + \tfrac{1}{2}ABsin[2\pi(f_c + f_m)t] + \tfrac{1}{2}ABsin[2\pi(f_c - f_m)t]}$$

The result is three terms, $\mathbf{Asin(2\pi f_c t)}$, the original carrier signal, and two other terms, one a little above the carrier frequency $\mathbf{(f_c + f_m)}$, and the other a little below $\mathbf{(f_c - f_m)}$. Together, this is known as ***amplitude modulation***. Each of these two terms a little off the carrier frequency is known as a ***sideband***, the higher one ***upper sideband***, and the lower one ***lower sideband***. When referring to one or the other sideband, we call each ***single sideband***.

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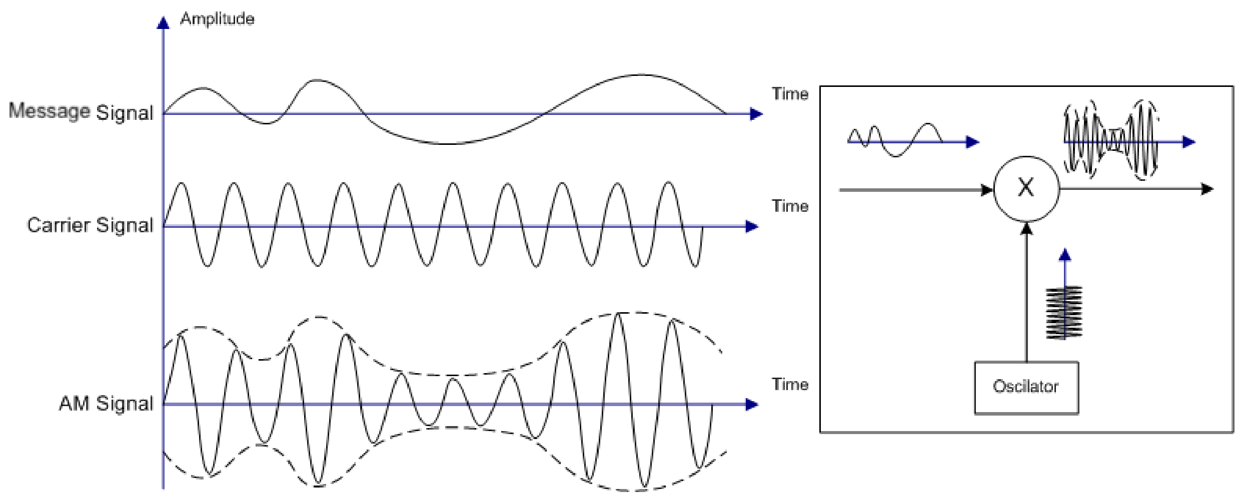
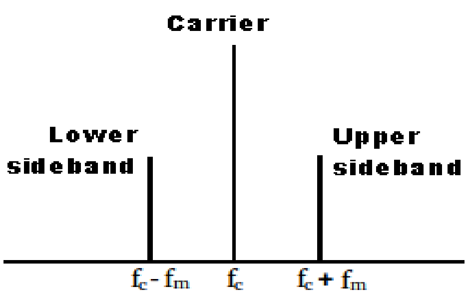
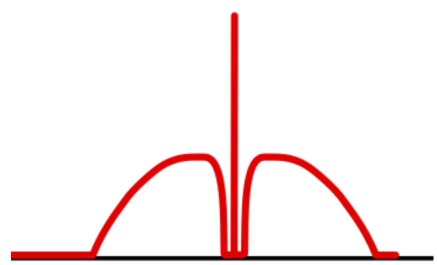
Amplitude modulation is also called double sideband because it contains both sidebands. After mixing the two (carrier and voice) signals together, the resulting signal might look like this:



The resulting time-domain signal can be represented in the frequency domain by using a Fast Fourier Transform, resulting in diagrams like these, a snapshot on the left, and real-time on the right, showing the frequency coverage on both sides, maybe during a spoken word:





As you can see from the equation, AM is made from the carrier signal plus two identical (actually, mirror-imaged) signals on either side of the carrier, and the difference between the highest $(f_c + f_m)$ and lowest $(f_c – f_m)$ signals $(f_c + f_m) – (f_c – f_m) = 2f_m$ is known as the ***bandwidth***. But if both the transmitter and receiver can agree on which frequency the carrier is (the operator "tuned" to it), there is no need to transmit the carrier signal. Furthermore, since the two sidebands are mirror-imaged duplicates, there is also no need to send both of them.

This way, the radio needs only to transmit one of the two sidebands, selected by the operator, and omit the carrier. We say that the carrier signal has been *suppressed*, a function of the *balanced modulator*. It then becomes the responsibility of the receiver to detect the sideband signal, create and add its mirrored image, and re-insert the carrier (done by a BFO, beat frequency oscillator), thus re-creating the original AM signal, which is easily demodulated (decoded).

This is the theory behind single sideband, to reduce the amount of power necessary to transmit the voice, and reduce the amount of bandwidth occupied on the radio spectrum by the en-

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tire signal. So, when you, the listener, tune to an SSB frequency, you're actually tuning in to a non-existent carrier.

USB or LSB

Which bands require us amateurs to use USB and which require LSB? Well, *require* is a rather strong word in this case, because which bands require which sideband is not truly regulated, but is governed by a *gentleman's agreement*. This means it's permissible to use the opposite sideband from what's conventional on a particular frequency band. In general, here are the agreements for phone (voice) operation:

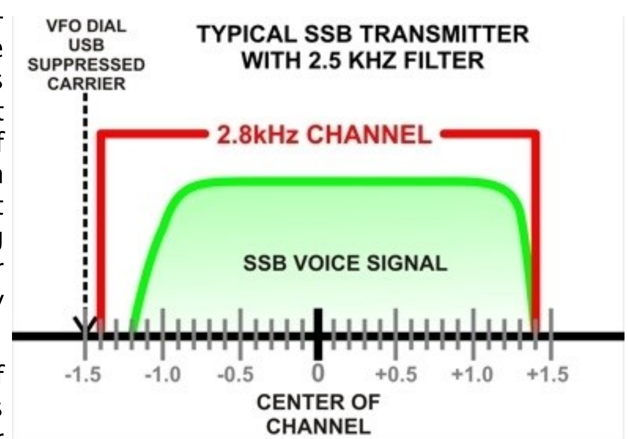
Band	SSB
160 meters 80 meters 40 meters	LSB
All others	USB

Some amateurs like to say that all frequencies below 10 MHz use LSB, but that's not the case. Also, among the exceptions to this is the RTTY digital mode, which uses LSB in the US and USB in the UK, regardless of the frequency. Another is the 60-meter band, for which voice operations must use USB.

By the way, you might have noticed that when discussing voice operation on HF, we haven't discussed FM, which is the primary mode for 2 meters, like many of us are used to. FM is very difficult to operate on HF because of a technical reason (rule Part 97.307.f.1) that severely limits its operation. The technical limitation arises from the large bandwidth (~10 kHz for narrowband and ~15 kHz for wideband) required to support conventional FM to preserve the audio fidelity you're accustomed to. So, you will likely never hear FM on HF frequencies.

Bandwidth

We discussed the fact that an AM signal occupies twice the bandwidth of an SSB signal. We also saw mathematically that an SSB signal has a bandwidth of about $\mathbf{f}_m$, but how much is that in Hz? Since $\mathbf{f}_m$ depends on the frequency of your voice, that'll depend on your pitch. Then again, by convention most transceivers limit the frequency range of the voice actually being transmitted to between 300 Hz and 3 kHz, or 3000 Hz, giving the operator a somewhat boxy sound.



The ideal human ear has a detection range of about 20 Hz to 20 kHz, but human speech falls way short of this range, depending on gender

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and other factors, such as whether you have a cold. In the world of telephony, the usable voice frequency range is set by agreement through research to about 300 Hz to 3.4 kHz, so most phone equipment is designed for this span.

Amateur radio manufacturers have agreed to further limit single sideband transmissions to 3.0 kHz, to help you, the operator, assure sufficient separation from an adjacent signal if it's 3.0 kHz from your target frequency. And the range is set to 3.0 kHz to support communication, not *fidelity*. Some bands, such as the 60-meter band, further limit that maximum. Some modes, such as CW and FT8, take the limitation even further.

If it hadn't occurred to you already, the lower end of the SSB bandwidth starts at a modulation frequency $\mathbf{f}_m$ at about 300 Hz. This means there is a slight (obviously 300 Hz) gap between the non-existent carrier frequency and the nearest frequency of the sideband signal (lowest pitch of the voice). This gap is not important, but is part of the discussion, because it occupies a portion of the bandwidth.

SSB effects

One thing you might notice when working HF using SSB is that when two stations double (transmit over each other), you can hear them both, which we refer to as a *pileup*. This is because they don't have those carrier signals interfering with ("beating against") each other.

Another thing you might notice is that when you key up without talking on HF using SSB, your output power meter registers nothing, because you're not transmitting a carrier signal. Therefore, if you key up on SSB by accident, but don't say anything, there's no need to announce your call sign, like you'd need to do on 2 meters FM.

A side effect to SSB transmissions is the fact that many new amateur operators believe their antenna to be near-perfect because their SWR meter shows 1.0:1 when they key up. It looks perfect because there's no reflected power, because there's no forward power, because your transceiver never sent your antenna a signal with any power. To measure SWR with your transceiver, you should instead transmit a signal that uses a carrier, such as CW or AM. I recommend you place more faith in your antenna analyzer, however, to provide a more accurate reading.

Finally, the generation of a SSB signal requires sharp cutoff characteristics of the sideband suppression filter in the balanced modulator, which "removes" the carrier and the opposite sideband signals. Also, SSB receivers must be manufactured with more precise tuning than that of AM or FM receivers.

Summary

Single sideband is the primary voice mode of operation that's used on HF, but can also be used on most other bands. It's a refinement of amplitude modulation; that is, it's AM, but without the carrier signal and the opposite sideband. Upper sideband and lower sideband are the names of the two AM sidebands, and different amateur bands use them by convention rather than by rule. The bandwidth of SSB is half that of AM, and is set by convention on HF bands. SSB does have some interesting side-effects, not the least of which is a pileup.

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